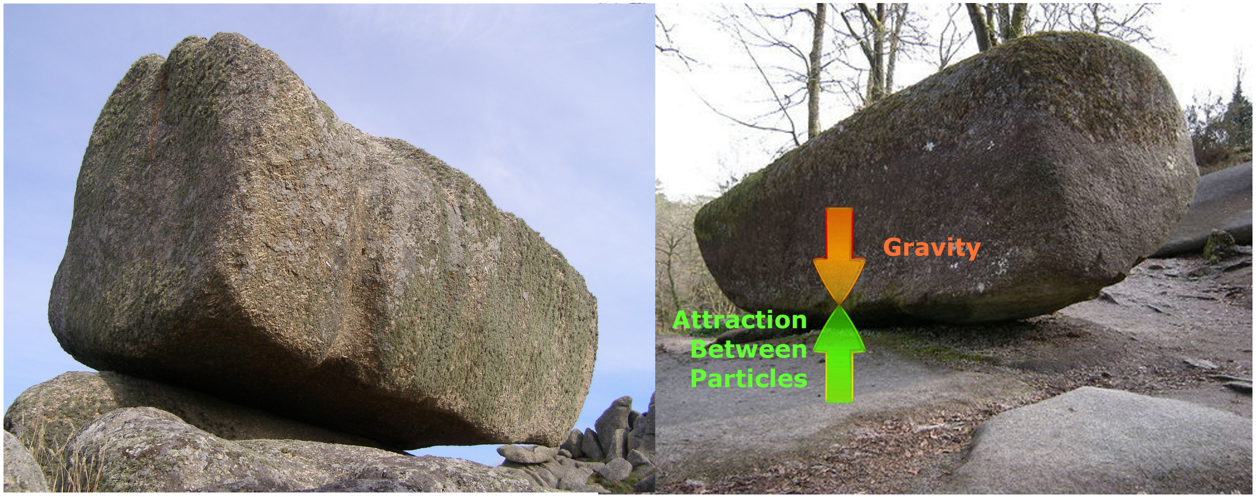
Solids, liquids and gases

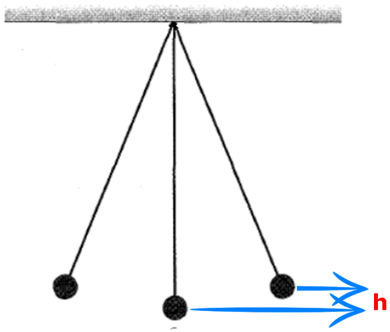


Swinging stones are a popular natural wonder. Stones which are more than a hundred tons in weight can be moved by a single human being. {Picture above} Careful examination shows that the large boulder is touching a lower boulder in a small area. The upper boulder is not moving towards the earth. So according to Newton's law, there must be a second force to oppose the force of gravity. But the source of the force is not electric repulsion. It is the force of attraction between particles of the lower boulder. If such a force did not exist, the lower boulder would have been turned into powder by the weight of the large boulder above. So far, the small particles subject to the forces of gravity and electric repulsion were not identified. The earth and the moon were considered to be made of small particles since this was needed for a mathematical description of gravity. Here, when properties of solids, liquids and gases are examined, the small particles will be identified.

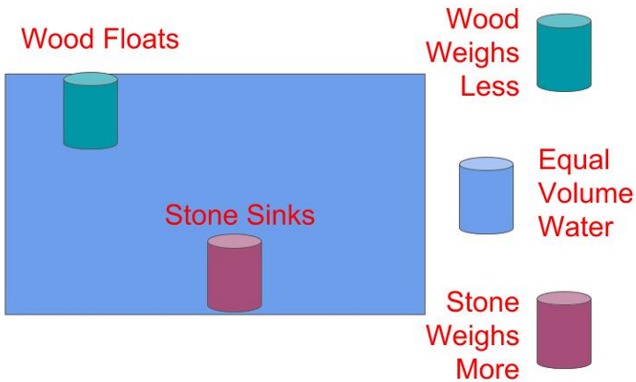
We can push a stick into sand but not into a solid stone. Sand is made of small solid particles. But there is no force of attraction between them. Sand cannot be used to build walls. Dry sand forms a heap. The largest possible angle for a heap of sand is 25°. {Picture below left} It is difficult to even walk over dry sand. But one can run on slightly wet sand. Wet sand can also be used to make beautiful sculptures.{Picture below right}

Quicksand is said to form when sand or mud is mixed with water in a specific ratio. Anecdotes are endlessly shared about how difficult it is to escape from quicksand. There are elaborate descriptions of how to “swim” through quicksand and escape. But dangers of quicksand have never been proved in a laboratory. Stories of people having lost their lives in quicksand have never been verified.

Sand can form heaps. Liquids cannot. A liquid flows when there is the smallest incline. Rivers flow thousands of kilometers into the sea. The average slope of a river bed is about



one meter per kilometer. To understand how small this incline is we can compare it with the swing of a pendulum. At the end of the swing the bob of the pendulum is slightly higher. {Picture left} This gives the bob of the pendulum a small amount of potential energy. This converts to kinetic energy as it swings. One meter per kilometer is equal to the bob of a one meter long pendulum being moved through an angle of 2^o or the bob being raised by one millimeter, one thousandth the length. But such a small slope is enough for rivers to flow for thousands of kilometers and join the sea.

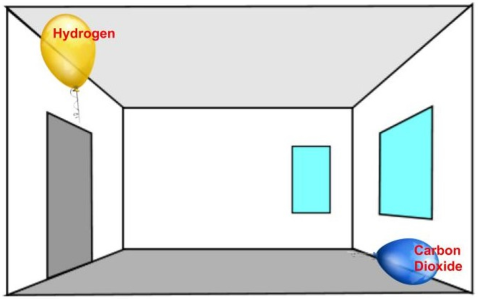


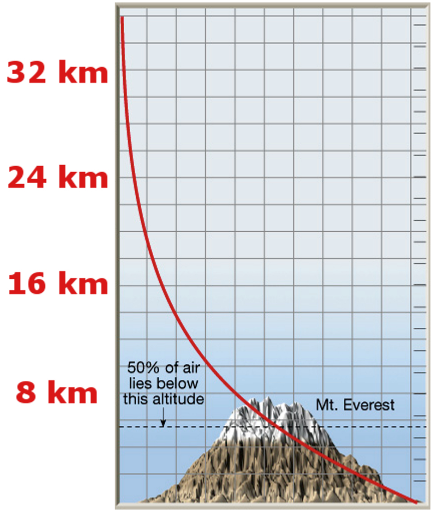
One stone can bear the weight of another stone. But a liquid cannot bear its own weight. That is the reason, liquids spread even on a horizontal surface. One could say that the lower layer of water in the sea is bearing the weight of the upper layer. But that is not correct. The solid surface at the bottom is bearing the weight of all the layers of water. If a volume of water at the surface is replaced by a stone of equal volume, the stone sinks. If we replace the volume of water with equal volume of wood, the wood will float. {Picture above right} The lower layer of water can only bear the weight of the water above or a block of wood of equal volume if the weight is lower. The stone, with a larger weight than equal volume of

water sinks. This is the famous principle of Archimedes. If a steel sewing needle is introduced vertically into water, it will sink. If it is slowly placed horizontally, it will float. Even on a perfectly flat horizontal surface water will not spread too far. More viscous the liquid, the less it will spread. These results show that the properties of the bulk of the liquid are slightly different from the layer at the top.

Solids and liquids are obviously made of small particles. But are gases also made of small particles? We can feel the pressure of the wind. Small particles floating in air become visible when a light coming through a small hole is viewed from an angle. {Picture left above} But these are not particles of the gas. When there is no wind, these small particles settle on any horizontal surface as a layer of dirt. So how to confirm that gases, like solids and liquids are made of small particles other than the dust?

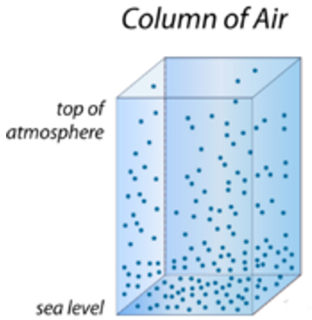
When common kitchen ingredients, vinegar and baking soda are mixed a gas is released. This is captured in a balloon and labelled carbon dioxide. Similarly, another gas is released by the reaction of drain cleaning fluid with aluminium kitchen foil. This is also captured in a balloon and labelled hydrogen. When these balloons are left in a room, the balloon labelled carbon dioxide sinks to the floor, while the one labelled hydrogen rises to the roof. {Picture right} Archimedes principle explains the results. The balloon of carbon dioxide is heavier than an equal





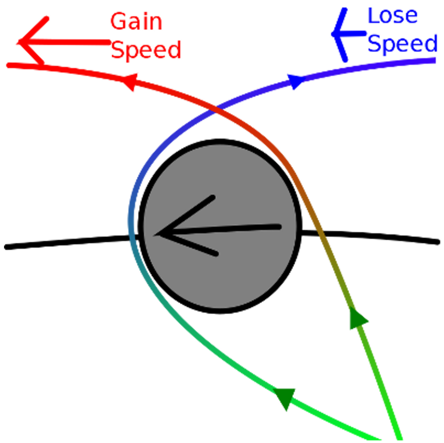
volume of air. The balloon of hydrogen is lighter. These simple experiments show that gases are also made of small particles, that they have weight and move because of the gravitational force.

People trying to climb the mountains of the Himalayas, some of which are 7 to 8 km high, find it difficult to breathe. The atmosphere around the earth starts becoming thinner as we go higher. Almost 50% of all the gases in the atmosphere are below a height of 5km. {Picture top left} Clearly there is one difference between the small particles that make up solids and liquids and the small particles that make up gases. Unless there is an obstruction, solids and liquids drop down to the sea level because of gravitational force. But only some part of the gases in the atmosphere reach sea level. Once again, from Newton's law, there must be a force opposing gravity acting on the small particles of gases. {Picture bottom right} When a stone is thrown upwards, it reaches a height and then drops back. So how are the particles of gases continuously able to get energy to oppose the force of gravity? Heat energy at the center of some stars opposes the force of gravity and prevents it from becoming a blackhole. Similarly, heat or thermal energy allows the particles of gas to continuously keep moving. Higher the temperature, more the thermal energy. But temperature determines only the average kinetic energy of the



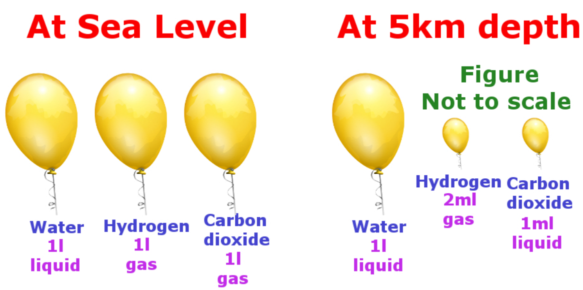
particles of gas. When the particles of gas collide or repel each other, as with snooker balls, their momentum changes. Sometimes the speed of the particles increases and sometimes it decreases.{Picture bottom right} Because of these changes, on an average, 50% of the gases in the atmosphere stay below the height of 5km. When we closely examine, particles of gases like hydrogen and helium have higher speeds and completely leave the earth's atmosphere. Particles in solids and liquids also have thermal energy. But the particles are strongly attracted to each other. So they do not have kinetic energy. But the thermal energy causes the particles to vibrate or sometimes rotate.

It is not easy to mix solids. Some liquids like water and milk mix easily. Some others like oil and water do not mix. However, all gases mix very easily. That is the reason you can smell a flower from a distance. One obvious conclusion. There is a lot of empty space between particles of a gas. Why are the balloons filled with hydrogen and carbon dioxide having a stable shape? The game of snooker described earlier gives a clue. Small particles of the gases inside and outside the balloon are always hitting the rubber balloon. If the momentum given to the balloon from both sides is not equal, there is a net force on the balloon surface, the balloon expands or contracts till there is no force. The force acting over a square meter of area is called pressure. The balloon size changes till the pressure inside and outside are equal. At this point, the balloon shape and volume will stop changing. If we place the balloon on a drum and pump more air into it, as the



pressure inside the drum is increased the balloon volume decreases. {Picture right}

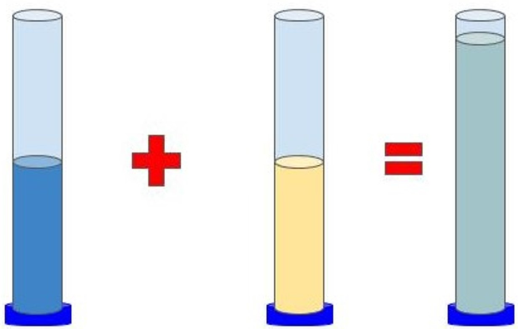
What happens if three balloons each of one litre volume and filled with water, carbon dioxide and hydrogen are immersed in the sea to a depth of 5km. Assume for the moment that the sea water temperature has not changed with the depth. Even though the pressure has thus increased enormously, there is no change in the volume of the balloon filled with water. A decrease in volume of one part in ten million would be noticed if the measurements are very accurate. The volume of the balloon filled with hydrogen will reduce to about two milliliters. That is a decrease in volume by a factor of 500. The volume of the balloon filled with carbon dioxide will be one milliliter. Moreover the carbon dioxide would have turned into a liquid. {Picture bottom left}



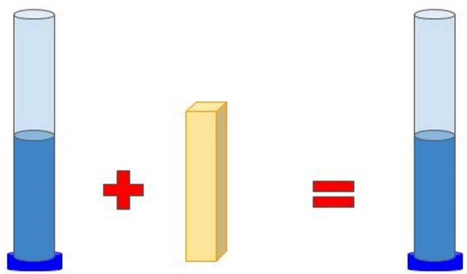
These results show that the small particles in water, carbon dioxide and hydrogen not only differ in their mass but also in the way they attract or repel each other. These forces depend on the distance between the particles. The particles present in water strongly repel each other. That is why the volume does not decrease. The repulsion between the particles of hydrogen is much

less. That is why the volume decreased by a large amount. The repulsion between the particles of carbon dioxide gas changed into an attraction. Volume reduced by a factor of 1000. So the average distance between particles has reduced by a factor of ten. But once a liquid is formed the particles repel each other. Further increase in pressure will not reduce the volume. In another experiment, 100 milliliters of water are added to 100 milliliters of ethyl alcohol. The volume of the mixture is only 192 milliliters and not 200 milliliters as expected. {Picture below} One can add 140 milliliters of a chemical called potassium nitrite to 100 milliliters of water and the volume does not change.

Clearly there are differences in the electric attraction and repulsion of the particles of various materials, be they gases, liquids or solids and the forces depend on distance between the particles. Understanding these changes will help us understand a large variety of experiments. We will next consider what these small particles are.



100 ml Water + 100 ml Alcohol = 192 ml



100 ml Water + 140 ml Potassium Nitrite = 100 ml solution